ONE DECADE OF ROBOTICS IN CONSTRUCTION

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ABSTRACT

Research and development of robotics in construction was started about a decade ago. History of the construction robot R & D is reviewed, and also steps of R & D and diffusion is discussed.

Start of International Symposium on Automation and Robotics in Construction (ISARC) took a role of big trigger to promote international co-operation, and foundation of its sponsoring association (IAARC) is reported.

Finally, as a result of questionnaire survey, construction robot R & D activities in major nine countries and problems to be solved are analyzed.

1. INTRODUCTION

Construction industry has been substantially contributing to our society through constructing infrastructures such as our homes, office buildings, factories, stations, harbors, bridges, dams, tunnels, roads, and so forth. Also we have to spend huge man powers for maintaining these social assets.

Construction operations were previously understood as very tough jobs to the human workers because of their dirty, dangerous and hard working conditions. Furthermore, people were suffered from continuous cost up by less increment of productivity and also lower wage rate than other advanced type of industry.

For solving these problems, people who are involved in construction industry, started research and development of construction robotics since a decade ago.

In this paper, the author would like review history of construction robot research, development and diffusion, and consider future direction of progress.

2. DAWN OF CONSTRUCTION ROBOT AGE

Construction robot research and developments were not systematically started.

Those activities were independently and started in parallel in some countries in the world.

For example in the United States, the construction robot research was started by some universities which had robot

research organizations already, and then they forwarded to co-operate with general contractors, military and atomic power develop organizations and so forth.

In France, the robot research was started by joint organization of national robot research and construction technology research.

In Finland, a government organization, Technical Research Center led the construction robot R & D from the beginning stage.

In Israel the robot research was started at a national university and continued systematically.

In Germany, the robot research was started from huge arm development for handling heavy work pieces, placing concrete and so forth.

In United Kingdom, the robot research was started by universities, general contractors, and then extended to the national research project.

In Japan, the construction developments were started under co-operation with general contractors, construction machinery manufacturers, university professors and government officials.

The triggers which urged construction robot research were the following items;

1) Diffusion of industrial robots in manufacturing industry and success to increase productivity stimulated constructing industry

2) Necessity to decrease high accident rate and insure safety of orerators

3) Removing dirty and hard manual work

4) Cutting working hours by increasing labor productivity

5) Recruiting young work forces into construction industry by image change of the industry

3. STEPS OF CONSTRUCTION ROBOT RESEARCH DEVELOPMENT AND DIFFUSION

At the beginning stage of the research, many people had doubt on the possibility to automate construction work by introducing construction robots. Therefore, research and development in this field was started by pioneering effort of some brave researchers and engineers.

The research and development activities in many countries can be classified into the following eight steps;

1) Survey of robotization needs into construction industry
On this stage, significance of the robotization was discussed, and then, priority to introduce the robots by type and part of construction work, target level to increase productivity and so forth are surveyed.

2) Analysis of the robotization conditions
In construction industry, there are more difficult

conditions than in the case of robot introduction into manufacturing industry such as:

a. Complexity of the working conditions

b. Robots must have locomotion and intelligent functions.

c. Robots must work in the out door, dusty and wet environments.

d. Large scale and weight work pieces are handled, and robots must meet such heavy duty conditions.

e. There are many complex group operations.

f. Robots have to be easily transported between construction sites.

For quantitatively grasping the robot system design conditions we need to analyze previous manual operations carefully.

3) Development of elemental robot technology, construction technology, system analysis and design technology which are fundamentally used for the robot R & D.

Many types of technologies are needed for developing the robot, and we need to develop those original technologies in parallel with robot development.

4) Robot specification determination for the particular applications

Before the robot development we need to determine the expecting robot specifications for meeting real needs to the robots, and exactly showing it to the robot specialists.

5) Try and examine the robot system plan by using prototype models, computer graphic simulation models, and so forth

Construction robot systems are usually far bigger than those of manufacturing. Which means materialization of the robot system plan needs more cost and build up time. Developing scale down prototype and computer graphic models, and evaluating the robot system plan is a very important theme in this field.

6) Practical application of the construction robots

Totally more than one hundred types of construction robots were developed in the world today. They have been gradually introduced into construction sites, but almost of them are on the prototype evaluation or trial use stage, and few are commercially accepted.

7) Total site automation completion by introducing a fleet of robots and systematic utilization of them

Difficulty of construction robotization is coping with

complex job structure on the construction sites. In the case of manufacturing system robotization, we can find many places where only one robot can be utilized and effectively paid back the invested capital. But in construction field, many of operations are done by group operators and repetitiveness of them are very little.

Therefore, we need to introduce a group of robots into the construction site and systematically operate them. In construction robotization we have to solve such new theme which was not experienced in the robotization of manufacturing operations.

8) If commercialization of the robots (hard and soft wares) are achieved, and enough capacity of construction robot market is developed, then construction robot supplying business can be automonously grown them selves.

The author believes that real diffusion of construction robots must be practically done by contribution of the robot commercial suppliers as a business and not by financial aids of government, legal support etc.

From that standpoint of view, we need to do our big effort for building up a new industrial structure for fully supporting construction robotization. For real utilization and diffusion of construction robots, it is necessary to accomplish all of these eight steps of conditions. In many countries, at the present stage, it is considered that majority of the research results reached the fifth step and partially could reach the sixth step.

But, as previously discussed in this article, for achieving substantial labor saving by robotization in construction industry, we must realize the seventh step, too. It means that the effective robotization in construction industry is far difficult than that in manufacturing industry.

4. START OF INTERNATIONAL SYMPOSIUM ON AUTOMATION AND ROBOTICS IN CONSTRUCTION

In 1984, Prof. D. Sangrey of Carnegie Mellon University proposed to start the first international symposium on robotics in construction at Carnegie Mellon University in the United States. That was immediate after his visit to Japan and met with many of robot research people in construction field.

It was said that, at that time, he felt strong necessity of international exchange of information in this field after discussed with foreign leading construction robot research people, and it became the trigger to start such international event.

Since that time the international symposia were held in the following places and greatly contributed to promoting R & D and diffusion of construction robots globally.

1st	symposium	Pittsburg, U.S.A.	1984
2nd	"	Pittsburg, U.S.A.	1985
3rd	"	Marseilles, France	1986
4th	"	Haifa, Israel	1987
5th	"	Tokyo, Japan	1988
6th	"	San Francisco, U.S.A.	1989
7th	"	Bristol, U.K.	1990
8th	"	Stuttgart, Germany	1991
9th	"	Tokyo, Japan	1992 (Scheduled)
10th	"	U.S.A.	1993 (Scheduled)

By continuous effort of organizing and scientific committee members, speakers and related people, today the symposium become the most prestigious and informative event in the world. Many of government officials, architects, general contractors' managements, construction engineering company officials and university professors have participated, and deepened mutual understanding. Start of International Association on Automation and Robotics in Construction (IAARC) as a sponsoring organization for International Symposium on Automation and Robotics in Construction (ISARC) is considered as the important result of international co-operation in this field.

5. CONSTRUCTION ROBOT RESEARCH AND DEVELOPMENT ACTIVITIES IN THE WORLD

Appendix:1 shows the recent construction robot research and development activities in major nine countries. The author made a questionnaire survey and collected informations about the construction robot research and developments from the leading specialists in each country. Results of the survey shows the following common trends in automation and robotics in construction.

1) In all countries the R & D activities were eagerly carried out and those are accelerated after the middle of 1980's.

2) R & D activities were started from elemental hardware technology and progressed to combined theme of them, and finally they are seemed to be synthesized as construction automation system.

3) There are similar research themes in several countries. If those projects are merged or co-operated each other, we can save man powers and cost for carrying out the project greatly.

4) For finding the enough places to utilize the research results, founding the international construction automation and robotics information center will become more significant.

6. PROBLEMS TO BE SOLVED

Appendix II shows the result of the questionnaire survey of problems to be solved which were presented by experts of major construction robot R & D countries.

From the result, we understand that we have many common problems in automation and robotics in construction, and there is a big possibility to co-operate for solving the problems.

The followings are summary of them:

1) Robot Technology
   a. Build up data base
   b. Co-ordination of planning of robot handling task
   c. Reliable robot and control system
   d. Communication system
   e. Power supply by new batteries

2) Construction Technology
   a. Develop construction process for robotization
   b. Normalizing packaging loads
   c. Introduction of prefablicating technology
   d. Better understanding of construction technology of the robot developing people
   e. Quality improvement by robotization
   f. Implementation of robotized construction system

3) Management
   a. Shortage of skilled construction workers
   b. Better organization of construction works
   c. Safety consideration
   d. Man/robot interface

4) Industrial
   a. Lack of interest in robotics by local constructors
   b. Ill suited organizational structure for construction automation
   c. High rate of occurrence of industrial illness and injuries.

5) Legislative
   a. Qualification of robot operators
   b. Safety regulation
   c. Minimize environmental pollution

6) General
   a. Clarify R & D themes for construction robotization
   b. Establish public construction robot research laboratory.

7. CONCLUSION

As briefly reviewed we are eagerly developing automation and robotics in construction industry for solving problems and make the industry more efficient and attractive.

In the case of robot introduction into manufacturing industry, it is said that they took two decades from the beginning to reach the stable state of robotization in the industry.

In construction industry, we have to cope with particular difficulties and accomplish robotization in shorter period of time by transferring technologies, ideas and experiences from manufacturing industry to construction ones. As a result of questionnaire survey, we learned that we have many common problems in robotization of construction work and those are more easily solved by world wide co-operation. This co-operation will be greatly enforced by start of the new international academic organization for construction automation and robotics.

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2. Proc. 1st Symposium on Construction Robotics in Japan (Japanese), 1990
3. Special Issue for Construction Robotics, Architectual Product Engineering, No. 271 (Japanese), 1988
4. Summary Report of Construction Technology Development Vision, Advanced Construction Technology Center (Japanese), 1990
5. WASCOR III-1 Research Report, System Science Institute, Waseda University, 1990

APPENDIX I

QUESTIONNAIR 1: CONSTRUCTION ROBOT R & D ACTIVITIES

1. United Kingdom

No	Organization	Theme	Period	Output
1	Advanced Robotics Construction Group (Taylor Woodrow)	Development of Advanced Robotics for Inspection: Maintenance & Repair of Buildings & Structures.	'88 - '90	Project Definition Study Conceptual Design Specifications
2	Advanced Tunnelling Group (British Coal)	Development of Advanced Robotics for mining with emphasis on a system approach & continuous operation	'87 - '89	〃 〃 〃
3	Advanced Robotics Underwater Group (Ferranti & Technomara)	Development of two demonstrator vehicles for inspection, maintenance & repair of offshore structures & a fully autonomous untethered vehicle for survey & inspection of the sea floor	'88 - '90	〃 〃 〃

2. GERMANY

No	Organization	Theme	Period	Output
1	Reymann GMBH, Ainedter	Computer controlled concrete panel work Robots placing steel bars	'82 -	Breakthrough More than 10 plants built
2	Putzmeisk, AEG, IPA, et al.	Manipulators large reach	'86 -	Breakthrough 3 machines sold 1 prototype
3	KFK	Manipulators large scale	'87 -	Fundamental research
4	ex. DDR Science	Robot removing plasters	'83 -	Prototype working
5	Joseph Vogele AG	Sensor controlled road construction	'88 -	Breakthrough
6	URACA GMBH	Hydrodemolisher Cartesian Robot	'87 -	〃
7	WOMA GMBH	High pressure water robot	'86 -	1 prototype
8	Liebberr GMBH	Control system for telescopic cranes	'88 - '89	Breakthrough
9	O & K Kissing	Control systems for excavators, etc.	'84 -	Partial Breakthrough
10	Herrenknecht GMBH	Various micro tunneling robots	'83 -	Breakthrough
11	Hochtief, IPA	Robot to renew brick sewers	'89 -	1 prototype working Orders for 2 more
12	Rohrtec GMBH	Robot for berstlining process	'82 -	Breakthrough
13	Kunz GMBH	Robot to renew rotatory sewers	'86 -	〃
14	Modern Technik	Manipulator for lifting bricks	'88 - '89	Breakthrough
15	FAC GMBH	Robot for handling bricks at the worksite	'89 -	1 prototype in operation
16	Noell GMBH	Concrete cutting robot for dismantle nuclear power station	'85 - '89	1 system in operation
17	Anliker GMBH	Brick wall erect machine	'86 -	Breakthrough
18	SUBA	Brick erecting robot	'84 - '88	1 system in operation

19	WTB - Augsburg	〃	'88 - '90	1 system in partial operation

3. FINLAND

No	Organization	Theme	Period	Output
*1	Technical Research Centre of Finland	Tiling robot	'89 - '91	Mobile robot prototype for interior tiling
*2	Partek Corporation	CAD/CAM system for freely shaped moulds for facade concrete components	'89 - '90	The production line for free shaped moulds in use & offered as a service
*3	Lohja Corporation	Precast wall panels & columns	'87 - '90	Operational pilot production line for wall panels
*4	Tampella Ltd., Tamrock	Autonomous drilling rig for surface applications	'89 -	Research underway
*5	Technical Research Centre of Finland	Robotization of frame construction	'88 - '92	Research undersay; Feasibility studies Experimentation results

Notes: *1 The system consists of a track based vehicle, an industrial robot, and process tooling. The robot performs wall cladding with ceramic tiles.

*2 Development of new features continues now.
The system provides a three-dimensional view of the surface, contour, quality, colour and patterns of the facade. The design data is transmitted to a manufacturing centre, where the mould is made of recyclable mould materials, rubber or metal. The system is especially meant for concrete facades with detailed decorations or demanding three-dimensional shapes.

*3 Shotcreting method is used in the productin of wall components. The component is moved in vertical position along the assembly line from one work stage to another. The shotcreting and the surface handling phases are mechanized and automated.

*4 This development is connected to the ESPRIT project "Panorama" which has been set the task of producing an advanced perception and navigation system. Several European organizations participate in this project, where Tamrock represents the end user.

*5 In 1988 - 1990, crane automation and 3-D measurements have been investigated and experimented. In 1991 - 1992, the feasibility of robotized frame construction systems will be evaluated.

4. ISRAEL

No	Organization	Theme	Period	Output
1	NBRI Technion, I.I.T.	Conceptual planning of interior finishing robot	'85 - '86	Conceptual Design Report
2	〃	Adaptation of small robot (SCORBOT) to building & painting activities	'86 - '87	Adapted robot (* VTR & Report)
3	〃	Development of configuration through computer simulation	'87 - '89	Simulation program (* VTR & Report)
4	〃	Planning of robotized work	'87 - '89	Computer system (* Computer program & Report)
5	〃	Adaptation of large robot GFMS-700 to building, painting & tiling	'89 - '91	Adapted robot (continued) (* VTR & Report)
6	〃	Development of autonomous (by the robot) work planning system	'91 - '92	In progress
7	〃	Automation of crane	'89 - '91	〃

5. AUSTRALIA

No	Organization	Theme	Period	Output
1	RMIT	Construction Robotics in Domestic Building	1 year	

6. FRANCE

* The information of No. 1, 5, 6, 8, 9, 10, 11 & 12 is described in details in:
"Robotics in Construction: projects and perspectives" , Cahier du CSTB, No. 2412, May 1990, Paris, CSTB, 1990

No	Organization	Theme	Period	Output
1	CSTB IIRIAM AID	SOFFITO Mobile robot for finishing work	'85 - '87	First experimental mobile robot for builging operations in Europe
2	POTAIN SOGEA	EURO 9 Automated tower crane	'87 - '91	New product on the market
3	POTAIN CBC	ATLAS Large scale manipulator for building construction	'90 - '93	
4	POTAIN GIM	Automated gripper for crane handling	'90 - '92	
5	CYBERNETIX	〃	'88 - '89	Specifications
6	CEBTP	LEZARD Inspection of vertical surfaces	'88 - '89	Robot in operation
7	DUEZ	ARTEMIS Automated process for building construction	'88 - '92	Buildings aleady produced
8	LCPC ENSM CYBERG BJL	SIREM Positioning system	'89 - '91	Potential use for automated road construction
9	MICROMAINE LCPC	SIRRAH DISTER Positioning systems	'87 - '89	Commercial products
10	CSTB MICROMAINE	Laser positioning system for site applications	'88 - '91	Experimentation on site
11	CBC MIDI-ROBOTS	Positioning system using hyperfrequency signals	'88 - '89	Prototype
12	BONNA SAE, et al.	IUI Prefabricated concrete urban network with built robotized inspection	'85 - '90	New design of technical gallery

7. USSR

No	Organization	Theme	Period	Output
1	Institute for Problems in Mechanics, the USSR Academy of Science	Wall-climbing robots (WCR) for construction, inspection & maintenace of buildings	'86 -	Several versions of WCR developed & tested (for painting, cleaning, cutting, welding, inspection, fire fighting.)
2	MNTK, "Robot"	Robots for painting	'89 -	Robots for painting of buildings

3	Stroydormash	Technological lines for production of bricks Mobile robots & cranes for construction	'86 -	Lines Several versions of robots
4	Institute for Machine Sciences, the USSR Academy of Sciences	Drives for robots	'86 -	Various drives for robots
5	NII Avtogenmash	Technological equipment (TE) for construction robots	'90 -	TE for robotized cutting & welding

8. USA

No	Organization	Theme	Period	Output
1	John Deere, Inc.,	Tele-operated excavation machine		John Deere 690C
2	Gradeway Const Co. & Agtek Development Co. Spectra-Physics	Automatic grading control for earthwork		Laser-Aided Grading System
3	Miller Formless Systems Co. Gomaco	Placement of concrete sidewalks, curbs, & gutters		Automatic Slipform Machines
4	American Augers	Tele-operated micro-tunneling		Micro-Tunnelling Machine
5	The Robotics Institute, Carnegie Mellon Univ.	Autonomous excavation, sandblasting, spray washing & wall finishing		Robotic Excavator (REX)
6	〃	Mapping subsurface pipes		Autonomous Pipe Mapping
7	〃	Autonomous navigation		Terregator
8	〃	Concrete core sampling for radiated settings		Remote Core Sampler (RCS)
9	〃	Nuclear accident recovery work, wash contaminated surfaces, remove sediments, demolish radiation sources, apply surface treatment, package & transport materials		Remote Work Vehicle (RWV)
10	MIT	Construction of interior partitions Metal track studs		Wallbots
11	〃	Construction of concrete masonry walls		Blockbots
12	〃	Weld shear connectors in composite steel/concrete construction		Shear Stud Welder
13	Univ. of Texas at Austin	Pipe bending, pipe manipulation & pipe welding		Automated Pipe Construction

9. JAPAN

No	Organization	Theme	Period	Output
1	MITI, Mechanical Engineering Lab.	Development of Robots for Extreme Environmental Conditions (8-year-project)	'84 - '92	Prototpes Reports
2	〃	Development of wall-climbing robots	'88 -	4 prototypes
3	MITI, Electrotechnical Lab.	Cooperative Teleoperation System	'87 -	MEISTER (Model Enhanced Intelligent & Skillful TEleoperation robot)

4	Ministry of Labor	Cooperative research of Safety & Hygiene in the application of industrial robots	'84 - '86	Enact Rules for Safety Safety education, etc.
5	Ministry of Construction, Advanced Construction Technology Development Center	General Technology Development Project Development of Advanced Construction Technology Systen through Electronics	'84 - '88	Report
6	WASCOR, research project of Waseda Univ.	Automation and Robotization Construction System Development of Module Robot Development of Supporting Technologies	'82 -	3D graphic simulation Annual reports Prototype Simulator
7	Ministry of Construction, Advanced Constructional Technology Development Center	Development of Construction Automation Technology	'91 -	Report
8	〃	Development of Automation Oriented Building Structure Technology	'91 -	Report
9	〃	Development of Prefebricated member production Technology	'91 -	Report
10	〃	Development of New Construction Technology Integration Methods	'91 -	Report
11	Ministry of Construction, Adevanced Construction Technology Development Center	Automation Technology Development of Tunnel Construction	'90 - '94	Report
12	〃	Automation Technology Development of Bridge Foundatin Construction	'90 - '94	Report
13	〃	Automation Technology Development of Road Pavement	'90 - '94	Report
14	〃	Development of Automation Oriented Concrete Structure Design and Construction Technology	'90 - '94	Report
15	Japan Society of Civil Engineers	Research committee activities for heavy structure construction robot R & D	'81 -	Report
16	Architectual Institute of Japan	Research comittee activities for building construction robot R & D	'85 -	Report
17	Building Construction Society	Research Committee activities for building construction robot R & D	'87 -	Report
18	Japan Industrial Robot Association	Several research projects for conceptual design of construction and maintenance robots	'78 -	Report
19	General Contractors Construction Machinery Manufacturers	Development of Construction Automation and Robot System over 100 types	'82 -	Prototypes Products on the market

APPENDIX II

QUESTIONNAIRE 2 : PROBLEMS TO BE SOLVED

1. United Kingdom

(1) System architecture and integration of software of various functions
(2) Control and communication
(3) Safety consideration to make the use of sutonomous robot machines, in construction operations, possible
(4) Addressing problems associated with man/robot interface
(5) Power supply provided by a new generation of batteries

2. GERMANY

(1) Qualification of personnel to run construction robots on work site
(2) Coordination of planning with the handling task of the robot
(3) Legislative action to:
- improve safety for the worker
- minimize environmental pollution (e.g. leaking sewers)

3. ISRAEL

(1) Development of a prototype on the basis of an adapted construction robot
(2) Implementation of robotized construction system

4. AUSTRALIA

The cost of development and general lack of interest in Robotics by local constructors.

5. FRANCE

The site organization is a prerequisite to the development of automation and robotization of construction operations.

Great efforts in using computers are made to solve these problems or organization.

These developments will lead to the creation of project data bases likely to be used by robots.

A part from this point, the problems to be solved to promote the use of robots are mainly:

(1) A better understanding of construction operation in order to be able to select tasks and to give specifications of robots
(2) A normalization of the packaging of loads (panels,

concrete forms, etc.)
(3) To convince construction people that the development of automation will improve quality (the decrease of danger will be a side effect)
(4) To develop specific construction process suited for automation

Automation is not considered as a final goal and before robots are really in operation on sites, we have to imagine intermediate steps with semiautomated processes to make easier and more reliable traditional operations such as measurements, positioning, control.

6. USSR

(1) Better organization and management of construction works
(2) Automatization and robotization of prefabrication technology
(3) Design of reliable robots and control systems for construction
(4) Technological equipment for construction robots
(5) Methods of climbing walls made of different materials

7. USA

(1) The lack of progress in developing construction robots
- The organizational structure in construction has been particularly ill-suited to facilitating meaningful work
- The traditional, craft-oriented structure of construction labor

(2) Necessity of developing construction robots
- 54 percent Higher rate of occurrence of work-related illness and injuries
- Shortage of skilled construction labor

8. JAPAN
(1) To clarify the themes of research and development necessary to automated construction work system.
(2) To define the ideal robotized construction system (and research for the future Conputer Integrated Construction System)
(3) To continue developing the related technology or skills
(4) To make the base materials or data base, using the developed technology or skills
(5) To establish the research laboratory for supporting the development of construction robotics and automation
(6) To restructure organization of construction industry for adapting automation and robotization of the industry